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13. ABSTRACT (Maximum 200 words)

A feasibility study was performed to determine whether a low-cost, high-performance diagnostic and treatment display could be developed to aid a medical specialist (Army medic, civilian paramedic) and guide a non-specialist in an emergency situation. As part of this project, knowledge-based software was developed to prescribe treatment for gunshot wounds of the abdomen and render a preliminary assessment of organ damage. The system pays particular attention to the identification and classification of hemorrhagic shock and emphasizes early detection of a rapid downturn in patient status. A design concept for a self-contained handheld unit is outlined. The unit consists of three key sensors (blood pressure, pulse, pulse oximeter) that are linked to an embedded PC-based controller. System software includes an expert system and a medical knowledge base that runs under a real-time operating system (QNX). It provides decision-making support, requests user inputs when needed, suggests a treatment regimen consistent with medic/paramedic protocols, and arrives at a preliminary diagnosis. The software design anticipates the emergence of dry fibrin sealant technology as a means of controlling external hemorrhage in the field. The unit's role is to assess the risks of using fibrin sealant versus its benefits, to continuously monitor the trauma victim for a change in condition, and to propose treatments when adverse reactions to fibrin sealant are encountered.

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Introduction

Both the Army medic and the civilian paramedic must react to the trauma situation in a time-critical fashion. With the advent of low-cost high-performance computers, high-speed data acquisition devices, and highly evolved shells for expert systems, the tools necessary for revolutionary changes in computer-aided diagnosis and treatment are available for the first time. The rapid availability of information and medical sensor inputs provides the foundation for the proposed knowledge-based system. This makes it possible to greatly improve the treatment of trauma victims in both the military and civilian populations.

The knowledge-based system examined in this study provides important decision-making support currently unavailable for on-the-spot trauma care. Data from several physiological sensors are combined with a knowledge-based system to greatly enhance the emergency treatment of trauma victims. In essence, the system serves as a computerized trauma support team. As a result, suggested treatments can be more specific to a particular injury, and the implementation of protocols can be enhanced without adding a great deal of complexity. This is evident in the Phase 1 study where the classification of acute hemorrhagic shock was added along with an early detection algorithm for rapid downturns in patient status. The diagnostic and display unit also serves as an aid to emergency personnel who are less trained than medics/paramedics. This is important in situations where the number of trauma cases overwhelm the medical delivery system or in cases where trained medics or paramedics are simply unavailable at the scene of an emergency. The computerized unit also facilitates the triage process subsequent to a major natural disaster (e.g., a large earthquake) or in the event of mass casualties on the battlefield.

Program Objectives

This study entails a partnership between Geospace Research, Inc. (GRI) and Loma Linda University Medical Center (LLUMC). The current study is aimed at demonstrating proof-of-principle for a diagnostic and treatment display unit. This is a knowledge-based system applicable to both the Army medic and the civilian paramedic/emergency medical technician (EMT). The feasibility study focuses on the diagnosis and treatment of gunshot wounds (GSWs). On a yearly basis, LLUMC handles ~1400-1500 trauma cases, of which ~13% involve gunshot wounds.

The principal objectives of the investigation are listed below along with the institutional participation (shown in parentheses). The key objectives are to:

1) select and implement the most advantageous knowledge-based engine (i.e. the inference software) for implementation on a compact (handheld) diagnosis and display unit. (GRI)

2) establish a procedure for the fusion of diverse types of medical information into a data base and implement this procedure to establish the system knowledge base. (LLUMC and GRI)

3) determine the primary physiological sensors necessary to meet the needs of the Army and civilian medical facilities and explore the viability of admitting optional sensors and special-purpose medical equipment under computer control. (LLUMC and GRI)

4) secure and process an existing LLUMC data base containing case histories relevant to the Phase 1 subtopic of GSWs. (LLUMC and GRI)

5) determine a commercially viable level-one hardware design for the self-contained diagnosis and treatment display unit and establish the hardware interface for the medical sensors. (GRI)

6) verify the accuracy and completeness of the system. (LLUMC and GRI)

7) demonstrate the proof-of-concept system using computer-generated sensor inputs and data from physical examinations performed in the field setting. (LLUMC and GRI)

Scope of Knowledge-Based System Development

On October 1, 1996 GRI personnel met with members of the LLUMC team headed by Ms. Paula M. Johnston, Director of Trauma Services. The LLUMC team consists of trauma specialists including physicians/surgeons, paramedics, paramedic liaison nurses, and executive personnel from the LLUMC Trauma Department. The purpose of this meeting was to better define the scope of the research effort and initiate the gathering of knowledge for the diagnosis and treatment display feasibility study. Because of the severe complexity of gunshot wounds, Ms. Johnston highly recommended that a section of the body be singled out for detailed study. The recommendation was to focus on gunshot wounds to the abdomen. Many issues exist including the path of the gunshot through the body, the range at which the shot was fired, the type of gun, nature of organ damage (e.g., bladder, liver, spine, etc.), and the level of hemorrhagic shock.

A consensus emerged that if GSWs to the chest were selected rather than a wound to the abdomen, many complications would arise that could not be fully considered in the limited time

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frame of the Phase 1 study. Considerations include a chest tube, possibly opening the chest, tension to the thorax, needle insertion between the second and third costal, intubation, nicks to the heart wall, spinal damage, and diaphragm trauma.

In general, GSWs represent the most prevalent source of serious penetrating trauma in the civilian arena. Handguns, shotguns, rifles, and, to a lesser extent, knives account for the majority of penetrating and perforating wounds. In military combat, penetrating and perforating wounds make up the majority of battlefield wounds. Most are produced by metal fragments from explosive devices, such as aerial bombs, artillery and mortar shells, and mines. In modern mechanized warfare, only 15 - 20 % of such wounds result from rifle and machine gun fire [Wiener and Barrett, 1986]. Although the civilian mix of penetrating trauma is not identical to that of military combat, the pathophysiology is similar enough to justify the use of GSWs in the feasibility study.

In summary, the Phase 1 study focuses on GSWs of the abdomen. A knowledge-base program consistent with EMT protrocols was constructed to provide a "preliminary diagnosis" and suggest treatment procedures for the trauma sustained by the victim. The program guides the user through the primary and secondary surveys performed by an EMT-II, determines whether immediate transport is required (i.e., load-and-go), establishes the class of acute hemorrhagic shock, accepts automatic sensor inputs from a computer file, and provides a written evaluation of patient status, trauma decisions, suggested treatments, and measured/observed medical parameters (e.g., vital signs, airway status, skin temperature, moisture, and color, etc.).

The Real-Time Expert System

Geospace Research, Inc. performed an extensive survey of inference engines currently on the market and carefully investigated their relevance to the present project. The products of twelve companies were examined including those of Acquired Intelligence, Inc., IntelliCorp, Inference, Comdale Technologies, Template Software, and others. Detailed examinations of the operational capabilities of the many commercially available engines led us to conclude that the Comdale/X expert system shell is best suited for the project.

<u>Overview of Comdale/X</u>

Comdale/X allows us to develop an expert system knowledge base that can be queried by a user. It runs under Microsoft Windows 3.x, which facilitates the development of a prototype system.

A QNX (an operating system that is a derivative of UNIX) version of the software is also available. This allows us to take the knowledge base developed under Windows and embed it in a portable, ruggedized system without having to port it to a different knowledge engine. Comdale/X supports forward and backward chaining, rule confidence estimates, system confidence reporting, rule priority assignments, as well as a choice of inference strategies. It also supports procedural programming with object oriented features such as class and inheritance. In addition, it supports dynamic data exchange under Windows, which provides a convenient means of supplying the knowledge base with an independent source of sensor readings.

From a medical standpoint, it is paramount that inference rules be correctly prioritized and that decision trees be properly executed with regard to primary and secondary trauma surveys. This requires that restraints be applied to the expert system so that it conforms to the highly structured EMT protocols. The knowledge base is provided with "medical judgment" which allows it to assess the relative importance of sensor and observational data inputs and the degree of certainty that can be attached to a given medical measurement/observation.

Technical Description of Comdale/X

The Comdale/X knowledge system uses so-called "keyword triplets" as the main building block in the assembly of the knowledge base. A triplet has two forms; it is expressed either as object.attribute.value or class.attribute.value. An object is a physical or conceptual entity (e.g., blood_pressure.systolic.@f, where @f is a floating point value). A class represents relationships between similar objects or classes in a hierarchical and schematic way. An attribute is a property associated with an object or a class. An object or class may have multiple attributes, each of which have separate values. A value may be logical (Boolean), numerical, a string, a date, or a time. Logical and numerical values are used extensively in our medical application; time is an important value appended to all sensor/observational data.

The Comdale/X engine invokes a basic strategy to guide the inference process. This strategy can be used to control forward and backward chaining. Forward chaining is a problem solving technique in which conclusions are drawn (or decisions made) by starting with known facts or observations. Backward chaining is a reasoning method that starts with the desired goal and works backward, looking for facts and rules that support the desired outcome.

In forward chaining, the system starts with facts and observations, then selects rules which utilize these facts to infer other facts. The new facts are then used to propagate the decision chain leading to the firing of new rules. On the other hand, sometimes the knowledge-based system is in need of information about a keyword triplet in order to evaluate an expression. If this keyword triplet can be identified in the conclusions of rules, the program will execute the appropriate rules to obtain the information. The process of selecting rules based on a need to identify triplets in their conclusion is an example of backward chaining.

Three important issues arise in forward and backward chaining. These are: the search strategy, the conflict resolution mechanism, and the focus mechanism. Consider, for example, that at some point in the inference process the program is presented with a number of keyword triplets with which to forward chain. The focus mechanism is used to decide which triplet will be used first. After selecting this triplet, there may be a number of rules which use the triplet to generate new facts. These rules form what is known as a conflict set. The conflict resolution mechanism is used to decide which of these rules will be executed first. The search strategy is used to decide if the system should forward chain as soon as new information is found or only after all rules in the conflict set have been examined.

In the case of a backward chaining scenario, the focus mechanism is used to decide which keyword triplet will be used to propagate backward chaining when more than one is eligible. The conflict resolution mechanism is used to elect one rule from a set of eligible rules. The search strategy is used to decide if backward chaining will terminate as soon as the keyword triplet is known or when that triplet is known with the highest possible certainty (i.e., when all rules in the conflict set have been examined or the triplet is assigned 100% certainty, whichever comes first).

In the present project, the correct expression of rules and their prioritization are critical because rules constitute reasoning knowledge and therefore handle complex relationships between medical observations, sensor data, and other factual material. Indeed, this is a key component in the transfer of information from LLUMC to GRI to the knowledge base. In general, rules can embody vague concepts, simple heuristics, or mathematical expressions.

Suggested treatments take the form of procedures. A procedure is a collection of instructions pertaining to rules, classes, or objects. Thus, depending on the nature of the rule and/or data, a medical treatment will be recommended. Essentially, procedures are used for

batch processing, as in the case of a list of medical treatment recommendations. A preliminary diagnosis arises from the knowledge base and the firing of appropriate rules. However, we fully recognized that an accurate diagnosis requires complex diagnostic examinations (e.g., roentgenographic studies; contrast studies such as urethrography, cystography, excretory urograms; and special diagnostic tests such as diagnostic peritoneal lavage and computed tomography) and/or surgical intervention (celiotomy).

EMT Protocols

The EMT protocol provides the necessary guide lines for the development of the knowledge base. This is an essential element in the treatment and diagnosis display unit. The standard Inland Counties Emergency Medical Association (ICEMA) protocols used by LLUMC form the foundation for the development of the knowledge base. However, GRI/LLUMC improved and extended these protocols by incorporating emergency medical information presented by *Copass et al.* [1991] and to a lesser extent elements of the physician's training guide assembled by *Mengert et al.* [1996]. A detailed outline of the unified protocol is provided in Appendix A. This protocol contains all components required to examine and treat acute abdominal trauma arising from GSWs; it does not specifically address trauma arising from GSWs in other parts of the body. As noted above, abdominal GSWs formed the focus of the Phase 1 feasibility study. The adopted protocols pay particular attention to identifying the threat posed by acute hemorrhage, classifying shock state, and monitoring patients for unanticipated, sharp declines in trauma status (so-called crash and burn victims).

If fully implemented for all trauma emergencies, the adopted protocol would completely specify the procedures and treatments employed by an EMT II. This level of emergency care is somewhat higher than that of the medical specialist outlined in the Army Field Manual for a Medical Specialist (FM 8-230) and somewhat lower than that of a special forces medic as described in the US Army Special Forces Medical Handbook (ST 31-91B). The most important differences lie in the fact that a medical specialist does not intubate a patient (as an EMT II does), whereas a special forces medic performs emergency field surgery (which an EMT II never does). Thus, the level of emergency care addressed by this feasibility study occupies the middle ground of the wide ranging expertise of Army medics.

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Operational definitions of many of the routine physiological signs assessed by an EMT are furnished in Appendix B. This is particularly useful for those who are not familiar with the medical surveys conducted by an EMT.

Classification of Acute Hemorrhagic Shock

Shock is a clinical syndrome in which the peripheral blood flow is inadequate to return sufficient blood to the heart for normal function. This abnormality of the circulatory system results in inadequate organ perfusion and tissue oxygenation. The identification and classification of shock is an operative tool for the diagnosis and treatment display.

During the Phase 1 project, particular attention was paid to the classification and control of hypovolemic (hemorrhagic) shock from the perspective of both the army medic and the civilian EMT. Proper classification of acute hemorrhage plays an essential role in both the diagnosis and treatment of trauma associated with penetrating wounds. Shock is often ranked as mild, moderate, or severe. However, in the case where acute hemorrhagic shock is involved, it is more appropriate to adopt the classification put forth by the *American College of Surgeons* [1981, 1994]. A table adapted from the recommendations of the American College of Surgeons is presented on p. 68 of *Copass et al.*, [1991] and is reproduced here as Table 1. Table 1 was augmented by LLUMC/GRI to include neck veins, skin color, skin moisture, and skin temperature as shock diagnostics. Additionally, CNS mental status was made more quantitative by referencing the Glascow Coma Scale. We have further expanded this table to include estimates of parameter importance and certainty. The final GRI/LLUMC revisions are displayed in Table 2.

The classification emphasizes the early signs and physiology of the shock state. Class I is uncomplicated shock characterized by the potential need for crystalloid fluid. Class II is also uncomplicated, but requires crystalloid fluid to effect resuscitation. Class III is a complicated state in which at least crystalloid fluid and perhaps blood replacement is required. Finally, Class IV can be considered a preterminal event. Unless very aggressive measures are taken, the patient dies within minutes. For the most part, a patient in Class III shock has a fairly good chance of full recovery, but complete recovery from Class IV shock is very unlikely because of lactic acidosis. In the knowledge-base program we included a shock Class 0. This is defined as

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Classes of Acute Hemorrhagic Shock* From *Compass et al.* [1991]

	Class I	Class II	Class III	Class IV
Blood loss in ml	up to 750 ml	1000 to 1250 ml	1500 to 1800 ml	2000 to 2500 ml
Blood loss in %[1]	up to 15%	20 to 25%	30 to 35%	40 to 50%
Pulse rate[2]	72 to 84 beats/min	100 beats/min	120 beats/min	140 beats/min, or greater
Blood pressure[3]	118/82 mm Hg	110/80 mm Hg	70-90/50-60 mm Hg	50-60 mm Hg
Pulse pressure (mm Hg)[4]	36 mm Hg	30 mm Hg	20 to 30 mm Hg	10 to 20 mm Hg
Capillary blanch test	Normal	Positive	Positive	Positive
Respiratory rate	14 to 20	20 to 30	30 to 40	≥ 35
CNS mental status	Slightly anxious	Mildly anxious	Anxious and confused	Confused, lethargic

*Adapted from Committee on Trauma, American College of Surgeons: *Advanced Trauma Life Support Course*, 1981, p. 45.
[1] % of blood volume in an average 70-kg male.
[2] Assume normal of 72 beats/min.
[3] Assume normal of 120/80 mm Hg.
[4] Difference between systolic and diastolic.

Table 1.

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Table 2.

Classes of Acute Hemorrhagic Shock* Revised by LLUMC/GRI for Knowledge-Based System

Imp.†	Cert.‡		Class I	Class II	Class III	Class IV
0.7	0.4	Blood loss in ml	up to 750 ml	1000 to 1250 ml	1500 to 1800 ml	2000 to 2500 ml
0.0	0.2	Blood loss in %[1]	up to 15%	20 to 25%	30 to 35%	40 to 50%
0.9	1.0	Pulse rate[2]	72 to 84 beats/min	100 beats/min	120 beats/min	140 beats/min, or greater
1.0	0.9	Blood pressure[3]	118/82 mm Hg	110/80 mm Hg	70-90/50-60 mm Hg	50-60 mm Hg
0.0	0.1	Pulse pressure (mm Hg)[4]	36 mm Hg	30 mm Hg	20 to 30 mm Hg	10 to 20 mm Hg
0.3	0.2	Capillary blanch test	Normal	Delayed or None	Delayed or None	Delayed or None
0.2	0.7	Respiratory rate	14 to 20	20 to 30	30 to 40	≥ 35
0.8	0.8	CNS mental status		Confused	Confused	Confused and lethargic
					From GCS Verbal (1-3).	From GCS Verbal (1-3). Query for lethargic if Class IV is in doubt.
0.1	0.0	Neck Veins	Flat while supine			Apparently absent neck veins while supine
0.6	0.6	Skin Color	Normal	Pale	Pale	Pale or cyonotoic
0.5	0.3	Skin Moisture	Normal	Moist	Moist	Profuse
0.4	0.5	Skin Temperature	Normal	Cool	Cool	Cold

*Adapted from Committee on Trauma, American College of Surgeons: *Advanced Trauma Life Support Course*, 1981, p. 45.
†Weighting factor for importance of measurement in determining hemorrhage classification.
‡Assessed confidence factor for field determination of measured quantity.
[1]% of blood volume in an average 70-kg male.
[2]Assume normal of 72 beats/min.
[3]Assume normal of 120/80 mm Hg.
[4]Difference between systolic and diastolic.

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a state where there is blood loss, but organ perfusion and tissue oxygenation are only slightly diminished.

In constructing the shock algorithm for the diagnostic and display unit, we added a weighting factor for the importance of the measurement in determining hemorrhage class, and included a confidence factor for field determinations of the measured quantities. The adopted values are displayed in the two columns at the far left in Table 2. The product of (importance × certainty) gives rise to a primary weighting factor for each measured/observed quantity. This addition to Table 2 automatically leads to the elimination of three quantities from program consideration: blood loss in %, pulse pressure, and the status of neck veins. Blood loss (%) is redundant and fosters greater uncertainty than blood loss (ml). Pulse pressure is also prone to measurement error, and this information is already contained in the systolic/diastolic blood pressure measurement. Finally, the bulge of neck veins was determined to be too subjective for use in class identification.

Because of the nature of medical measurements made by an EMT and an Army medic in the field, the boundaries between the four classes of shock are not sharply demarcated. Notice that there is often overlap between observational parameters from different shock classes (e.g., blood pressure and respiration rate for shock classes III and IV). In other cases, nominal values are listed, but in reality they represent the mean values of distribution functions. This combined with a broad range of measurement inaccuracies gives rise to inexact transitions between shock states. A skilled EMT resolves the vagueness of the shock classification with the aid of experience and judgment. The knowledge-base program handles this situation through the use of "fuzzy logic." [see e.g., *Stefik*, 1995].

Fuzzy logic represents a means of quantifying the vagueness implicit in Table 2. In effect, it recognizes that people reason in shades of gray not just black and white. Implicit in the concept of fuzzy logic is the concept of "gradual membership" in a class. Characteristic functions are developed to determine how a parameter or set of parameters qualifies a trauma patient to be a member of a certain shock class. From a practical standpoint, fuzziness is added to keyword triplets involving blood loss, blood pressure, respiration rate, and pulse rate. Separate characteristic functions are developed for each parameter in each shock class. This exercise was performed in close collaboration with the trauma professionals at LLUMC. In each

shock class, a range of (non-fuzzy) parameter values are assigned a rank ranging from 0.0 to 100.0. This defines their corresponding membership values for a given shock class. (The characteristic function is expressed as rank versus parameter value for a range of values.) To determine shock class, "votes" are tallied from both fuzzy keyword triplets (i.e., blood loss, blood pressure, respiration rate, and pulse rate) and the non-fuzzy keyword triplets (capillary blanch test, CNS mental status, skin color, skin moisture, and skin temperature). Fuzzy keyword triplets are assigned weighting based upon rank, and all parameters are weighted by the product of (importance × certainty) in Table 2. In general, the shock class (I through IV) with the most votes is used to characterize the patient in the knowledge base. However, if the number of votes falls below a predetermined threshold, the patient is assigned to shock class 0.

The class of acute hemorrhagic shock is used in conjunction with GSW location/path to arrive at a preliminary diagnosis. This is discussed in detail in the following section.

Preliminary Diagnosis

In the case of abdominal GSWs, an exact diagnosis is sometimes difficult to render without surgical intervention. However, experienced trauma personnel are able to provide an "educated guess" as to the principal source of severe GSW trauma using data obtained at the field location. LLUMC and GRI have devised a "preliminary diagnosis" algorithm, which has been incorporated into the knowledge-base program. It is predicated primarily on the location of the GSWs and the class of acute hemorrhagic shock indicated. Essentially, the most important sources of viscera damage are assessed within the framework of shock-related symptoms.

For diagnostic purposes the abdominal cavity is divided into nine areas: epigastric, umbilical, suprapubic, right and left hypochondrium, right and left lumbar, and right and left inguinal. The division of the abdomen is illustrated in Figure 1.

Figure 2 shows the viscera present in each ninth section and the expected hemorrhagic shock class that is expected to ensue if the organ sustains major trauma because of a GSW. For example, if a trauma victim sustains a GSW in the middle right ninth and acute hemorrhagic shock of class 3-4 ensues, then the preliminary diagnosis will indicate that significant damage to the liver is likely. The adopted strategy cannot distinguish a small laceration of the liver from significant damage to the colon. In general, either a celiotomy, or a combination of

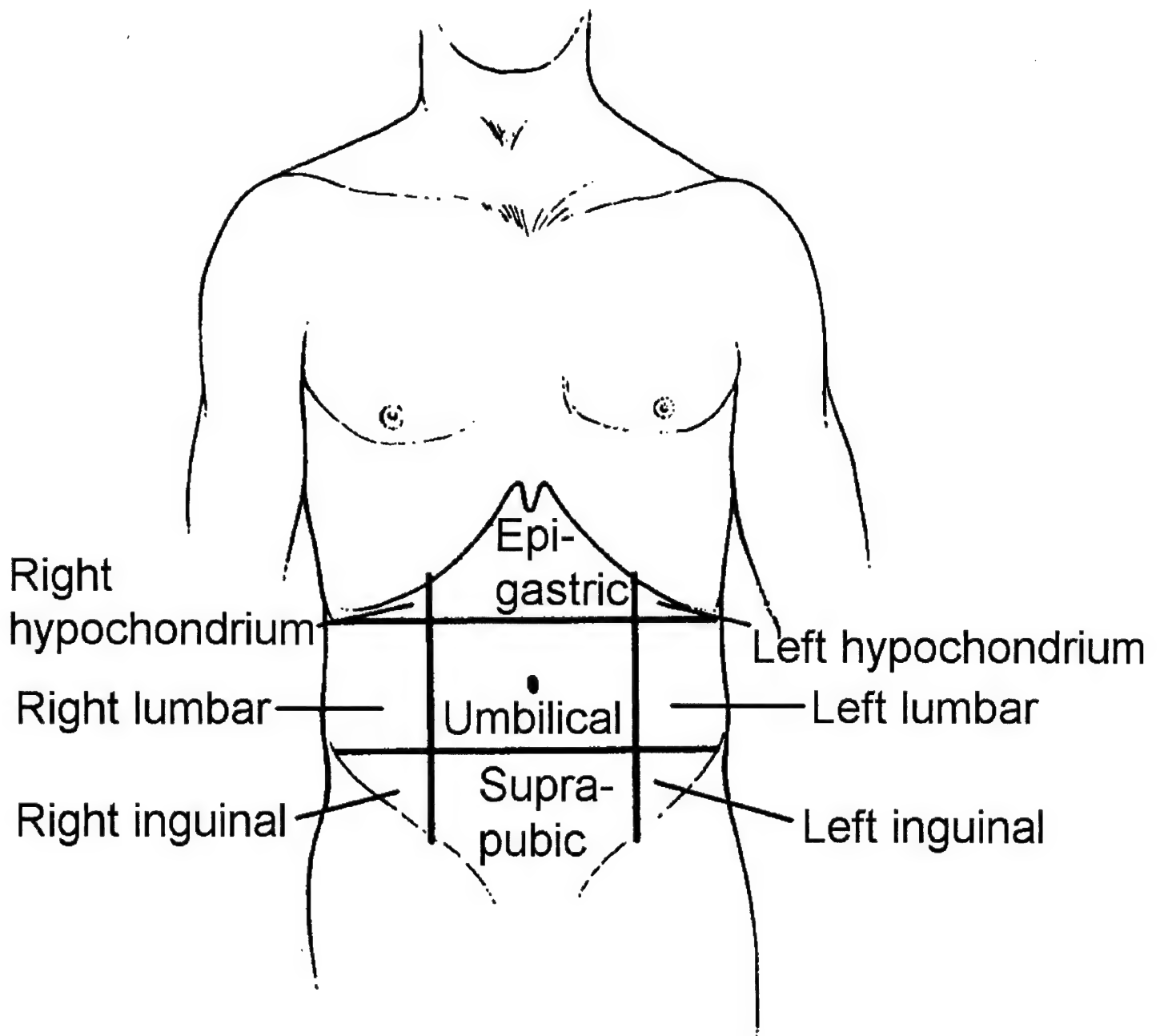# Sectioning of the Abdomen into Ninths for the Preliminary Diagnosis

Right hypochondrium

Epi-gastric

Left hypochondrium

Right lumbar

Umbilical

Left lumbar

Right inguinal

Supra-pubic

Left inguinal

Figure 1

Figure 2

Abdominal Ninth Sections

Upper Right Ninth		Middle Upper Ninth		Upper Left Ninth	
Organ	Hem. Class	Organ	Hem. Class	Organ	Hem. Class
Inferior Vena Cava	4	Aorta	4	Spleen	3-4
Liver	3-4	Liver	3-4	Kidney	2-3
Kidney	2-3	Pancreas	2	Pancreas	2
Colon	1	Stomach	1-2	Stomach	1-2
Diaphragm	1	Colon	1	Colon	1
Gallbladder	1	Diaphragm	1	Diaphragm	1
		Spine	0		

Middle Right Ninth		Middle Ninth		Middle Left Ninth	
Organ	Hem. Class	Organ	Hem. Class	Organ	Hem. Class
Liver	3-4	Aorta	4	Colon	1
Colon	1	Small Intestine	1	Ureter	0
Ureter	0	Spine	0		

Lower Right Ninth		Middle Lower Ninth		Lower Left Ninth	
Organ	Hem. Class	Organ	Hem. Class	Organ	Hem. Class
Colon	1	Small Intestine	1	Colon	1
Appendix	0	Rectum	1	Rectum	1
		Uterus/Prostate	1		
		Bladder	0		

Peritoneal	Retroperitoneal	
Large and Small Intestines	Inferior Vena Cava	Uterus
Liver	Aorta	Colon
Gallbladder	Spine	Rectum
Stomach	Kidneys	Pancreas
Spleen	Ureter	Uterus
Uterus/Prostate		

roentgenographic studies, bladder catheterization results, contrast studies, and special diagnostic examinations (e.g., peritoneal lavage, computer tomography) are needed for a detailed diagnosis.

The elementary model could be enhanced if the type of weapon, type of projectile, and the firing distance were known. In the case of civilian GSWs, all of these factors are generally not known. However, this type of enhancement may be more appropriate for military combat, where weapon types and distances are often better known. The severity of the wound is directly related to the amount of kinetic energy lost in the tissue (not solely the total energy of the projectile). The amount of energy loss is determined by: 1) the amount of kinetic energy possessed by the projectile at the time of impact, 2) the velocity of the projectile (above 2600-2900 ft/s tissue destruction becomes much more severe), 3) the yaw of a bullet at the time of impact, 4) the type of projectile (i.e. caliber, shape, construction, and configuration), and 5) the density, strength, and elasticity of the tissue struck by a bullet as well as the length of the wound track [e.g., *Di Maio*, 1993]. Thus, the overall evaluation is rather complex and only a limited amount of insight can be obtained from the ballistics alone.

Early Detection of "Crash and Burn" Situations

It is not unusual for a patient who initially appears to be in a stable condition at the trauma site to suffer a major decline during transport to a regional trauma center. A knowledge-based system can alert emergency personnel regarding a suspected downturn in patient status. LLUMC and GRI have developed a simplified algorithm to alert attending personnel of an impending "crash and burn" situation. It is based on a rapid rate of decline (2 mm/min) in systolic blood pressure and supported, in part, by corresponding increases in pulse rate (2 pulses/min or greater). However, in a trauma situation the variability of vital signs combine with measurement errors to make the corresponding decision making process more difficult. Under ideal conditions (which are never realized in trauma care) random errors in systolic blood pressure measurement are commonly determined by the instrument exhaust rate during a single interpulse interval. Generally, this translates into systolic pressure error bars of ±1-3 mm for a given measurement. Obviously, these error bars can be mitigated by fitting multiple measurements to a simple mathematical function (e.g. a low order polynomial). In this case, the errors are determined by the number of measurements available and can be relatively low ($\leq$ 1 mm/min). However, other factors related to the anxiety state of the trauma victim, whether the

victim is under the influence of alcohol or drugs, patient motion, and the measurement consistency of the EMT give rise to other uncertainties that are more difficult to estimate. These factors adversely impact the early detection of a crash-and-burn scenario by decreasing measurement certainty. In the knowledge base developed as part of Phase 1, an alert is given when the rate of change between two consecutive systolic blood pressure measurements exceeds 2 mm/minute. (Excluded from such calculations are estimates of systolic blood pressure based on the absence or presence of the radial, femoral, or carotid pulse.) When the initial alert is given, the EMT is instructed to carefully remeasure systolic blood pressure. A downward trend of 2 mm/min across three measurements and estimated error bars $\leq$ 1 mm/min are required before a warning is issued for crash-and-burn.

Treatment procedures that can be offered for a crash-and-burn situation are limited. If the trauma victim is being transported in an ambulance, three suggestions can be made:

1.   Increase the normal saline (NS) IV to the maximum wide open rate to delay a precipitous decline in blood pressure.
2.   Initiate a second large bore IV (if not already present) and run a second NS IV wide open.
3.   Increase the driving speed to the nearest trauma treatment center.

The effectiveness of the above approach increases with early detection of the impending decline.

A rapid decrease in systolic pressure is a necessary and sufficient condition for the identification of a crash-and-burn situation. However, an increase in pulse rate is a necessary but not a sufficient condition. Because of this, a change in the pulse rate provides supporting information which increases the certainty of the crash-and-burn declaration but is not in itself a valid indicator. Other indicators such as skin temperature and moisture are very subjective. They do not sufficiently increase the certainty of the decision making process to justify their use.

The Trauma Score and Triage

Trauma severity scores are developed for triage and as a reference to aid in comparing the outcomes of different patient groups based on a mix in case severity. Under normal civilian circumstances, triage is used to help pre-hospital and emergency personnel decide which patients must receive the specialized care of a trauma center. Usually a trauma center is able to render appropriate and necessary initial care to all presenting patients. Those with life-threatening or

potentially life-threatening problems are treated first. However, in the case of a battlefield evacuation or in community disasters (e.g., severe earthquake, hurricane, etc.) the number of patients and the severity of their complaints exceed the capabilities of emergency centers. In this situation, patients with the greatest chance of survival who require the least expenditure of limited resources (time, personnel, equipment, etc.) are treated first. Similar situations arise in the combat environment where access to comprehensive medical treatment is often limited.

The standard trauma score (TS) [*Champion et al.*, 1981] quantifies injury severity; it provides a numerical scale for the assessment of circulatory, respiratory, and central nervous system functions. In the prehospital, non-field setting, TS has been shown to accurately predict survival/death outcome for both blunt and penetrating injury patients [*Champion and Sacco*, 1983; *Sacco et al.*, 1984a,b]. For field triage, TS has been used alone as well as with information on injury type, mechanism of injury, and location of injury [*Champion et al.*, 1983].

The TS employs qualitative measures of respiratory effort and capillary refill as part of its scoring process. (See Appendix A). However, as *Champion et al.* [1989] point out, difficulties occur when the TS is calculated in the field. At night, capillary refill and respiratory expansion are difficult to determine, and retractive respiratory expansion is always difficult to observe day or night. In the Phase 1 knowledge base, we have included an estimate of patient survivability based on the Revised Trauma Score (RTS) described by *Champion et al.* [1989]. The RTS excludes both of the above measurements from consideration.

The so-called "Washington Hospital Center data base" (2,166 patients) was used to develop the RTS, and the "Major Trauma Outcome Study" (26,000 patients) was employed for validity testing and for the final determination of the weighting coefficients. As a predictor of patient outcome for all types of penetrating trauma, the RTS is a little more accurate than the TS. However, the RTS provides a significantly better model for determining the severity of a head injury in comparison with the TS.

The RTS is calculated as follows:

$$RTS = 0.9368 \text{ GCS} + 0.7326 \text{ SBP} + 0.2908 \text{ RR},$$

where GCS, SBP, and RR refer to the Glasgow Coma Scale, systolic blood pressure, and respiratory rate, respectively. Values of RTS range from 0 to approximately 8. *Champion et al.*

[1989] list survival probability P_s determined from regression analyses for integer values of RTS. These values are displayed in the table below.

RTS	P_s
8	0.988
7	0.969
6	0.919
5	0.807
4	0.605
3	0.361
2	0.172
1	0.071
0	0.027

In the knowledge base developed during the Phase 1 study, the above table is replaced by a ninth order polynomial to facilitate calculations of P_s for non-integer values of RTS. The interpolation can therefore be expressed as:

$$P_s = A0 + A1(RTS) + A2(RTS)^2 + A3(RTS)^3 + A4(RTS)^4 + A5(RTS)^5 + A6(RTS)^6 + A7(RTS)^7 + A8(RTS)^8 + A9(RTS)^9 ,$$

where the coefficients A0 - A9 are listed in the table below.

Coefficient	Value
A0	2.8102367323 E-2
A1	2.5138552134 E-2
A2	1.1331533531 E-2
A3	2.2924535580 E-3
A4	2.8594847349 E-3
A5	-6.1317921089 E-6
A6	-3.8037136874 E-4
A7	8.4641779634 E-5
A8	-7.0849919457 E-6
A9	2.1175982409 E-7

The calculated survival probability is provided in the output data file (History.xls) of the knowledge-base program (discussed below).

The use of trauma data sets that are category specific (e.g., military combat or a specific civilian disaster such as an earthquake) would probably improve upon the survival estimates of RTS. However, this type of analysis is beyond the scope of the current effort.

Description of the Software Package Developed During the Phase 1 Program

The complete software package and instruction guide entitled *Knowledge System Software for a Diagnostic and Treatment Display* has been sent exclusively to Dr. Stephen P. Bruttig, HQ U.S. Army Medical Research and Development Command, Combat Casualty Care Research Program, Fort Detrick, Fredrick, MD 21702-5012, (301-619-7591). This measure was taken because only a single user license was purchased for COMDALE/X. The software package without COMDALE/X is available from Dr. Frank T. Djuth, Geospace Research, Inc., 550 N. Continental Blvd., Suite 110, El Segundo, CA 90245.

Several program elements combine to form the software package developed during the Phase 1 program. They include the expert system (COMDALE/X), Geospace Research, Inc. (GRI) knowledge-base files that run under COMDALE/X, Microsoft Excel 4.0, and GRI Excel data files and macros, which supply the knowledge base with an independent source of sensor data through dynamic data exchange (DDE). All elements require Microsoft Windows 3.x. Technical details for how and why this configuration was adopted may be found in the software instruction guide.

Overview of the GRI/LLUMC Knowledge-Base Program

The knowledge-base program consists of three stages called EMT Assist, Cycle Driver, and Patient History. EMT Assist employs the EMT protocol for the primary and secondary surveys to gather data about the trauma victim. Additionally, EMT Assist suggests emergency treatment procedures consistent with ICEMA EMT-IA/II/P protocols employed by LLUMC. The primary survey provides an initial assessment of the airway, breathing, and circulation (ABC's) and external hemorrhage control. Vital signs are also obtained along with a neurological evaluation. The secondary survey consists of head-to-toe examination of the trauma victim in a rapid, systematic fashion. A patient may be given the highest transport priority and declared "load-and-go" after the primary survey. Alternatively, load-and-go conditions may arise during any portion of the secondary survey depending on the circumstances.

Upon completion of the secondary survey, Cycle Driver begins. In this phase of the program, sensor data (systolic/diastolic blood pressure, pulse rate, and respiration rate) are made available to the knowledge base at nominally regular, but not necessarily periodic, time intervals.

A macro written in Excel 4.0 is initiated by the user. Once started, Excel 4.0 makes the sensor data accessible to COMDALE/X. However, this does not mean that the knowledge-base program immediately processes all sensor data. The program monitors the patient for changes in condition, alerts the care provider when necessary, and recommends additional procedures as required. Emergency recommendations have highest priority and may delay the processing of new sensor data. Sensor measurements are furnished for time periods of the order of 20 to 30 minutes (the time required to transport a trauma victim to a trauma care center and initially treat the patient). However, time within the knowledge program runs ~15 times faster than normal. As a result, Cycle Driver generally lasts for about two minutes.

After Cycle Driver is finished, a log of the patient history is written to an Excel sheet entitled History.xls. This sheet includes a variety of information including the calculated Glascow Coma Scale (GCS) score, the Trauma Score (TS), the Revised Trauma Score (RTS) and the associated survival probability, input parameters provided by the user, treatments suggested by the program, the location of gun shot wounds provided by the user, a history of the vital signs supplied to the knowledge base, a list of possible organs damaged, and diagnostic indices. The value of a diagnostic index ranges from 1 - 4; this index is a measure of both the probability and severity of organ damage. In a given organ damage list, the relative probability that a particular organ is damaged is proportional to index value normalized by the maximum value in the list. The estimated severity of injury is proportional to the unnormalized index values. Finally, shock class determined by the knowledge-base program is listed in the patient log. Its determination is rather complex and relies on the use of "fuzzy logic." This aspect of the program is described above in the section entitled "Classification of Acute Hemorrhagic Shock."

Testing

Testing of the knowledge-based program was performed with the aid of numerous patient histories supplied by LLUMC. For the most part, civilian victims of gunshot wounds are 18-30 year old males. These demographics are reflected in the patient records examined as part of this project.

There are three types of records that chart the trauma treatment history. The first is the EMT record filled out by the emergency response team (usually from a fire department, private

ambulance company, or an air rescue service). This covers the time interval beginning at the arrival of the ambulance/air rescue helicopter at the scene of the incident and ending when the patient is transferred to the trauma care center (LLUMC). The second is the trauma room record provided by the emergency department at LLUMC. This documents the detailed results of the primary and secondary surveys performed in the trauma room of the hospital, provides a history of vital signs, lists interventions, procedures, and scheduled tests, and furnishes a nursing diagnosis. All events and treatments that occurred in the emergency room are listed in this record. Finally, there is a hospital summary record, which provides a complete report of the hospital stay beginning at admission and ending with patient discharge. Included in this record is injury data, prehospital and transfer data, a summary of the trauma team results, values for the RTS on admission and the TRISS (survivability) score, lists of treatments and procedures including surgical procedures performed, anatomical diagnoses, a description of inpatient care, and outcome/discharge data.

The first two reports furnish information about physiological indicators (e.g., skin temperature, moisture, color; GCS parameters, status of pupils, etc.) as well as the vital signs that are used as inputs to the knowledge base. The LLUMC summary report provides a decisive diagnosis, which is extremely important for testing the preliminary diagnosis offered by the knowledge-base program. Additionally, a decision tree is developed for each patient history to verify the knowledge-base program's understanding of the protocols as well as to ensure that GRI properly implements the protocols.

Sensors for a Prototype

As part of this project, we have investigated noninvasive medical sensors that are needed if the diagnosis and treatment display is to be effective. Additionally, we have emphasized sensor compactness, durability, and have attempted to find low cost solutions that do not compromise sensor performance.

From a medical standpoint, the following sensors are required: a blood pressure monitor, a pulse monitor, and a pulse oximeter to measure %SAO_2. In addition to these sensors, paramedic vehicles usually carry a Lifepack 10 heart monitor. This unit is the size of a brief case and has three leads that are attached to the upper chest (two on the right, one on the left). The unit records the cardiac rhythm, produces visual numerical values, audio alarms, and has

memory to store readings. The heart monitor is considered an optional sensor because of our emphasis on system compactness and our desire to control the cost of the overall unit. Other options such as interactive control of IV pumps are easy to implement but are not part of the primary sensor package.

In Phase 1, we examined commercially available sensors to determine whether they were appropriate for the diagnostic and display unit. This appears to be the case for the systolic/diastolic blood pressure monitors, which also measure the pulse rate. A variety of units is marketed as personal blood pressure monitors by AND, Omron, Lumiscope, Sunbeam, Walgreens, and Sunmark. We examined and tested digital units that were highly rated for consistency and accuracy by *Consumer Reports* [October, 1996]. The list prices for such units range between ~$50 and $110, but they are competitively sold in the Los Angeles market between ~$30 and $70.

Comparisons were made between the results of the automated digital units (with and without automatic cuffs) and a calibrated manual aneroid blood pressure monitor. We found that the top rated units were highly accurate. Moreover, they generated consistent readings within the error bars imposed by the unit's automatic exhaust rate and the pulse rate of the individual. LLUMC/GRI found that the performance of these units is medically acceptable for the diagnostic and display unit. In certain respects, they are superior to the manual blood pressure measurements routinely obtained in the field through palpation and/or auscultation. The emergency measurements are influenced by the rapid pace of patient transport and the loudness of the siren.

As part of this study, we examined both arm cuff and wrist cuff models. Although we know of no clinical comparisons between the arm and wrist cuffs, we found that the top rated units produced nearly identical results. The wrist cuff is more convenient to apply in an emergency situation. However, it is less effective than the arm cuff if the radial pulse is weak or absent (i.e. at systolic blood pressures near ~80 or less). As of this writing a firm decision on the arm versus wrist cuff has not been made.

GRI examined the electronics of two preferred models tested (AND model UA-702 and Omron model HEM-601). Although the plastic shell containing the electronics is large, the actual electronics package is rather small. Figure 3 shows the circuit board inside the highly rated UA-702. This unit was purchased for $30. The clear tubing in the figure connects to a

Figure 3

pressure/acoustic sensor (silver can with a white center to the right of the liquid crystal indicator). A single embedded controller/processor runs the unit (the chip below the liquid crystal indicator). The board contains other support electronics and wiring/regulator for the nine-volt battery which runs the unit. In general, this printed circuit board is under-populated with components and could be significantly reduced in size. Despite this, it is only 4 inches by 2 inches in size. Operationally, it is attractive to replace the liquid crystal display with an RS-232 interface and use it in its current form. However, as part of the Phase 1 study no tests for durability and ruggedness were performed, so such a judgment may be premature.

Pulse oximeters used to measure oxyhemoglobin $\%SAO_2$ are unlike the blood pressure monitors discussed above in that they are not mass marketed for individuals. Typically they are produced only for hospitals, physicians, and emergency aid personnel. In the current project, pulse oximeters would be used to alert the user to the presence of an airway obstruction or to the imminent development of an obstruction. It would also be very effective for the detection of pneumothorax and hemothorax.

A compact light emitting diode (LED) and photosensor serve as the detector for a pulse oximeter. However, although the detector is small, the processing unit tends to be bulky. Moreover, power consumption becomes an issue because of the LEDs used with the sensor. For the proposed diagnostic and display unit, a special battery power supply would have to be developed. The sensor could be used in its current form, but data processing would have to be performed by the unit's host processor. The theory of pulse oximeter operation is rather straightforward offering the possibility for an efficient analysis algorithm. A brief description of the analysis process is provided below.

With each heart beat, a pulse of oxygenated arterial blood flows to the LED sensor site, usually at the tip of a finger. Initially, the processor determines the amount of light absorption that occurs when the pulsatile blood is absent. This establishes the baseline for the combined absorption caused by tissue and nonpulsatile blood. Absorption is then measured after the next heart beat when pulsatile blood enters the tissue. The subsequent variation in absorption is attributed to the presence of a pulse of arterial blood. The processor must correct the data obtained during the pulsatile flow for the amount of light absorbed during the initial (non pulsatile) flow. The ratio of the corrected absorption to baseline absorption is then used to determine functional oxygen saturation, that is, oxygenated hemoglobin calculated as a

percentage of the hemoglobin capable of transporting oxygen (i.e., oxyhemoglobin and reduced hemoglobin). Dysfunctional hemoglobin cannot be measured with this technique.

Prototype Processor - General Considerations

<u>System Hardware</u>

In addition to developing knowledge-base software during Phase 1, we examined the types of system hardware needed to develop a portable, self-contained diagnostic and display unit. The hardware design depends on the architecture of the knowledge-base software. It must be able to efficiently run the knowledge engine. Thus, our hardware design followed the development of the software package.

<u>Host Processor</u>

From a commercial standpoint, it is necessary to develop a diverse product line that incorporates trade-offs between cost, flexibility, and mobility. This must be viewed from the frame of reference of the processor hardware. The processor must be capable of hosting the knowledge engine. Thus, if the knowledge engine requires a SPARC platform to run efficiently, a Pentium platform will not be adequate. The processor must be fast enough to search the knowledge base and execute all rules in a timely fashion. Additionally, it is highly desirable that there be enough computational power to support several instances of the software, that is, multiple patients. An adequate interface must exist for the sensors, and sensor readings must be available in real time. By real-time, we mean that the delay between a sensor value becoming available and the processor actually reading that value (assuming that no other tasks have higher priory) must be less than 0.1 s, regardless of processor loading or other I/O demands. This requirement demands both a sufficiently powerful processor and an operating system which is designed for real-time operation. The processor must also preserve the time history of sensor readings and perform sufficient signal processing to prevent false readings from being accepted. This entails data filtering and trend analyses of the sensor data. Thus, efficient floating point arithmetic is a strong requirement. A simplified user interface must be developed; data entry through either touch screen or function keys is necessary. Manual keying of entries must be kept to a minimum. Finally, the processor must be able to sound an alarm if the patient's condition is rapidly deteriorating. This implies that a process exists which monitors both the real-time trends of sensor data and the state of the knowledge base.

If an option is developed for real-time control of a patient's IV or O_2 flow, added emphasis must be placed on real-time response from the processor. If an option for providing telemetry to a base station is exercised, basic packet radio control protocols must be readily available to the processor.

Operating System

An integral part of the processor is the operating system. The selected knowledge-base engine must run under it in real time with multi-tasking capability. In the case of multiple patients, each patient must be managed as a separate task. Similarly, each sensor has an assigned task, that is, a software package designed to monitor the specific sensor, acquire and process data, and perform the appropriate signal processing and trend analysis. In the event that a telemetry option is included, the operating system must also dedicate a task to the packet radio system. For example, this task might include the capability to send data to a base hospital with error correction and a retry protocol as well as the ability to receive patient information from the hospital (if available). Finally, the user interface is a dedicated task required for operator I/O.

We have considered four hardware options for the processor: 1) a compact or notebook PC, 2) a small handheld "palmtop" unit, 3) a "palmtop" unit as a remote interface to a ruggedized "black box" embedded system, and 4) an ultra-light PC unit.

Notebook PC

This design entails the installation of the system on a notebook PC. Although PCMCIA interface cards could be used to control remote medical sensors via either IEEE-488 interface or through an analog-to-digital converter, it is generally not possible to operate both of these interface systems simultaneously with a notebook computer. This would artificially place a limit on sensor development.

The Notebook PC requires the smallest development costs. Although it is relatively easy to transport in a vehicle, it is unacceptable for most field applications. Moreover, Notebook systems tend to rely on keyboard inputs and most do not have a touch screen monitor. Additionally, the requirement of a Notebook PC forces the estimated unit cost above $2000. This is a relatively high-cost alternative that would be implemented only if there were major limitations on developmental resources.

Handheld Unit

A handheld computer, such as an Apple Newton or US Robotics Pilot could be used to run the system. This is similar to the notebook design, except that it would be smaller for ease of handling and less expensive to produce. A touch screen entry system would be employed. Although this unit has the advantage of extreme portability and ease of use, the sensor interface is extremely limited and it is incompatible with the most desirable knowledge-base engines. The estimated cost of this "Newton-like" unit is less than $1000.

Handheld Unit with a Remote Link to an Embedded PC-Based Controller

This system would make use of a PC-based controller wired to medical sensors and to a packet controller in cases where telemetry is desired. The embedded controller would essentially be a "black box" with no screen or keyboard. A ruggedized PC board/chassis would enhance system robustness, and a proprietary bus could be employed to greatly enhance system reliability. Rather than using an I/O board system with card edge connectors, the embedded system would use a pin connector system with locking screws maintaining positive pressure to prevent the loosening of data cards. The embedded PC would have no inherent limitation on the number of I/O connectors or the amount of available memory. RS-232C and IEEE-488 interfaces could co-exist with analog-to-digital converters. Ready access to external devices would also be available. The user interface would not necessarily have to be tied to the black box. Instead, one could use a wireless link to a handheld control unit (e.g., an Apple Newton or US Robotics Pilot). This would allow medical personnel to attend the patient while using the system. Either touch screen entries or stylus entries could be used. As a production item this unit is lowest in cost but requires a larger developmental effort.

Ultra-Light PC Unit

This option entails the design and construction of an ultra-light PC system. It could be made extremely rugged. A touch-sensitive LCD display would serve as the interface to the user. However, a keyboard and monitor could be used for test purposes. This unit is essentially a self-contained black box with a screen and data entry system. It is anticipated that this unit would be placed next to the patient and periodically accessed by the user. Medical data would be gathered from sensors connected directly to the system. Remote data links would not be employed.

Hardware Interface

Most medical instrumentation is designed for the IEEE-488 (i.e. HP-IB) interface. This is by far the most common interface. Additional low-cost sensors that are not amenable to the IEEE-488 interface could be monitored directly with the aid of analog-to-digital converters. Alternatively, an RS-232 interface could be incorporated into an existing sensor's design.

The host system's RS-232 serial interface would be used to communicate with a packet controller in cases where remote telemetry is desirable. Several commercial firms make packet controllers for the PC which use RS-232 lines. Additionally, the packet link could be operated at a low baud rate (1200 bauds/s) to make data transmission more reliable in shadowed regions.

As a supplementary option, one could embed a small GPS receiver in the unit and transmit location packets to the base hospital along with the medical telemetry. Such an option would only add a few hundred dollars to the cost of the telemetry system and would enable a trauma care center or an Army field hospital to determine the location of the incoming patient.

Prototype Processor - Specific Recommendations

Software System Design

We suggest that the COMDALE/X Real-Time Expert System be used as the developmental knowledge engine for the prototype system. While the prototype knowledge base would be developed under COMDALE/X, this program is not amenable to real-time operation because it runs under Microsoft Windows version 3.x. (The internal design of Windows makes it impossible to guarantee a sufficiently short latency period between sensor input becoming available and the controlling process being able to read that input.) However, other Comdale products do run under a real-time UNIX-like operating system, QNX. This requires that COMDALE/X be upgraded to the more powerful version, COMDALE/C.

QNX is an operating system designed for real-time operation on Pentium platforms. Moreover, it is compatible with the POSIX operating system standard. This standard requires a commonality between compliant operating systems such that software written for one POSIX system can be run under another POSIX system with minimal alteration. QNX consists of a small operating system kernel which supervises a group of cooperating processes. This improves efficiency and makes the system more responsive to external devices (sensors, controller, etc.). QNX supports distributed processing, which means that computer devices are

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transparent to the operating system; the operating system treats inputs from another computer, attached via a packet network or a remote RF link, the same way as the keyboard of the processor executing the knowledge-base program. With the aid of a Web server, QNX can simultaneously provide a trauma care center the same access to the system as emergency personnel at the trauma site.

Hardware Architecture

The low-cost design that appears to be most responsive to Army and civilian needs centers around the so-called "black box" concept, that is, a small light-weight rugged unit with an embedded PC-based controller. In addition to the controller, the black box contains the sensor interface, mass storage, and memory; it hosts the key software elements (the operating system, the knowledge engine, and the medical knowledge base). The primary sensors (e.g. blood pressure/pulse monitor and oximeter) are connected directly to the black box. For practical purposes, a touch screen display is recommended. There are three configurations for the screen display: 1) it can be part of the black box giving rise to a single compact unit, 2) it can be wirelessly connected to the black box via a local RF or infrared link, and 3) it can be directly connected to the black box with a cable. Configuration 1 yields a single light-weight self-contained unit, whereas in configurations 2 and 3 the display can be physically separated from the black box. Because sensors are directly connected to the box, it must reside close to the trauma victim. The advantage of configurations 2 and 3 is that the operator does not have to be next to the patient to make data entries.

For the black box controller, we suggest the Advantech PCM-5860 Pentium all-in-one single-board computer. This is essentially an entire Pentium on a small PC board. It uses the sturdy PC-104 bus to connect to peripheral cards, such as analog-to-digital converters and an IEEE-488 interface. This bus carries the same electrical signals as does a PC/AT bus, but it is physically connected by board to board stacking connectors, which are more robust than the card edge connectors typically used in desktop PCs. Each card is screwed into the stack and is more immune to vibration and oxidation of contacts. This configuration has a compact form factor. The board dimension is 3.6 inches by 3.8 inches, and the stacking separation is 0.6 inches. (This is part of the PC-104/IEEE-P996 standard for embedded PC systems.) PC-104 boards from Analogic and National Instruments could supply the necessary interfaces to the outside world

with the aid of direct analog-to-digital and digital-to-analog converters, as well as via the IEEE-488 bus and/or RS-232C lines.

For configuration 1, where the touch screen display is contained in the black box, numerous manufactured models are available. For remote touch screen displays (configurations 2 and 3), we suggest using either of two existing handheld systems: the Apple Newton or the US Robotics Pilot.

There are several commercially-viable options for the overall unit. In addition to the RF/infrared link to a handheld terminal, a packet link to a remote base is also available. Packet networking could be enabled using terminal node controllers (TNC) such as those developed by Advanced Electronic Applications. There are several choices, depending on the number of modes desired and the types of data transfers. Systems range from a simple 1200 baud packet TNC to a multi-mode data controller capable of falling back to 300 baud transmissions with powerful error detection and correction protocols as well as speeding up to 9600 baud when radio reception is clear enough for the higher data rate. Finally, position information could be incorporated into the packet transmission with the aid of a small embedded GPS receiver module. Two commercially available receivers that are ideal for this purpose are the SVeeSix-CM3 from Trimble and the Lassen-SK8.

Hemorrhage Control with Dry Fibrin Sealant Technology

During the Phase 1 program, GRI and LLUMC were in close contact with Dr. John B. Holcomb, a general surgeon at the Army's William Beaumont Surgical Clinic at Fort Bliss, TX. Dr. Holcomb's research in fibrin sealant technology served as a catalyst for our interest in fibrin sealants and their impact on the proposed diagnostic and treatment display.

Introduction

Uncontrolled hemorrhage from penetrating wounds is a major source of morbidity and mortality in both civilian trauma patients and combat victims. During the Vietnam war approximately 50% of combat deaths were caused by uncontrolled hemorrhage [*Bellamy*, 1984]. In the urban setting, trauma from gunshot and stab wounds has increased dramatically in the past decade. Firearms are responsible for approximately 33,000 deaths and an estimated 120,000 non-fatal injuries in the United States each year [*Caroline*, 1995]. The active control of bleeding

in the prehospital environment remains an important consideration in the survival of trauma patients.

Recently, there has been renewed interest in the use of fibrin tissue sealants to control hemorrhage by the US Army and the American Red Cross (ARC) [e.g., *Holcomb et al.*, 1997a]. Special attention is being paid to fibrin sealants because of their great promise in reducing civilian and military fatalities resulting from penetrating injury. If approved for Army use, a major reduction in the number of combat casualties with Class III and Class IV hypovolemic shock is anticipated.

Activated fibrin sealant reproduces the final step in the coagulation system. Thrombin is the final active enzyme in the coagulation cascade and fibrinogen is the precursor of the structural protein fibrin. Thrombin activates fibrinogen by cleaving fibrinopeptides A and B to produce fibrin monomer, which then condenses to form fibrin polymer. The speed of this reaction is determined by the concentration of thrombin; the maximal tensile and adhesive strength of the resulting material is determined by the concentration of fibrinogen [*Holcomb et al.*, 1997a].

In the US, "fibrin glue" used for hospital-based surgery is prepared by combining a mixture of bovine thrombin and calcium chloride with concentrated human fibrinogen (cryoprecipitate) directly in the wound [see e.g., *Kram et al.*, 1988]. Fibrin glue is being used in an ever increasing variety of clinical applications. These include solid organ injury, cardiac surgery, vascular anastomoses, closure of bronchopleural fistulae and dural defects, support for corneal and peripheral nerve repairs, fracture stabilization, reinforcement for bile duct closure, and the treatment of splenic trauma [e.g., *Berguer et al.*, 1991; *Kuzu et al.*, 1992]. It is generally recognized that the fibrinogen concentration is lower in locally-produced hospital formulations and greater in several of the mass-produced mixtures described below. Maximal concentrations are achieved with dry fibrin preparations [e.g., *Larson et al.*, 1995; *Holcomb et al.*, 1997b] and other similar dressings currently being investigated by the Army and the ARC.

In the era of World War II, fibrin glue, pre-polymerized sheets of fibrin foam, and fibrin films were mass produced as part of a joint military-American Red Cross (ARC) program. After the war, fibrin products were withdrawn because of the danger of hepatitis transmission. In 1978 all pooled human fibrinogen products were recalled by the FDA. However, plasma protein

purification techniques developed in response to the HIV epidemic led to much better techniques for removal/inactivation of viruses in the blood plasma fractionation process. This makes the use of human fibrinogen much safer than in the past and has lead to renewed interest in a ready-to-use form of fibrin sealant. Independent developmental efforts have been made in this area by the US Army's Letterman Institute of Research and by the ARC. A fibrin dressing consisting of powdered fibrinogen and thrombin on a removable silicone gel backing is currently available [*Holcomb et al.,* 1997b]. A more refined dressing is being developed which replaces the silicone gel with an absorbable mesh [*Holcomb et al.,* 1997a]. This packaging arrangement requires no refrigeration, prehydration, premixing or blood bank support. Consequently, it holds great promise for the treatment of trauma victims in the field [*MacPhee,* 1997].

Adverse Reactions and the Need for Additional Research

The appropriate means of using fibrin sealants to aid trauma victims remains an active topic of research. Fatal cases involving the application of hospital-formulated fibrin glue to deep hepatic wounds in humans have been reported by *Berguer et al.* [1991]. An alternative treatment strategy involving a balloon tamponade device has been suggested by *Poggetti et al.* [1992] because of concerns related to fibrin glue. In the past, research studies with animals have shown that the intravascular injection of thrombin can result in immediate disseminated intravascular coagulation [*Malik,* 1986; *Malik and Horgan,* 1987], fibrin microembolization in the lungs [*Minnera et al.,* 1987], neutrophil and platelet activation and deposition in the lungs [*Malik and Horgan,* 1987; *Zimmerman et al.,* 1985], pulmonary endothelial injury [*Malik,* 1986], pulmonary edema [*Minnera et al.,* 1987], release of arachidonic acid metabolites and platelet aggregating factor [*Malik and Horgan,* 1987], and the activation of the complement cascade [*Malik and Horgan,* 1987]. *Berguer et al.* [1991] point out that the clinical manifestations of thrombin-induced reaction in animals include immediate systemic hypotension, pulmonary arterial vasoconstriction, decreased cardiac output, and arterial hypoxia. These physiologic disturbances last approximately 15-20 min and gradually dissipate (if the animal survives). However, the severe and/or fatal hypotension encountered by *Berguer et al.* [1991] was not apparent in several recent studies conducted on animals [e.g., *Kuzu et al.,* 1992; *Salvino et al.,* 1993; *Larson et al.,* 1995; *Jackson et al.,* 1997; *Holcomb et al.,* 1997a; *Cornum et al.,* 1997]. These studies entailed the use of fibrin glue to treat splenic trauma, arrest an

intraparenchymal abdominal hemorrhage, and control hemorrhage in a femoral arteriotomy, an extremity gunshot wound, a grade V [*Moore et al.*, 1995] hepatic injury, and a radical retropubic prostatectomy.

Principal concerns regarding the use of fibrin sealants on humans include the local development of intravascular microemboli or infarction, general embolism (particularly pulmonary embolism), and precipitous hemodynamic collapse caused by a systematic adverse reaction to bovine thrombin. In accounting for the sudden hypotension observed in two patients, *Berguer et al.* [1991] suggest two possible causes: an anaphylactic reaction to bovine thrombin, and a direct activation of the coagulation cascade with resultant disseminated intravascular coagulation and vasomotor shock. *Holcomb et al.* [1997a] indicate that antibody responses to commercial bovine thrombin may be attributable to vasoactive impurities (e.g., Factor V) rather than to the thrombin itself. If this were the case, improved purification of thrombin would yield a solution to the problem. Nevertheless, at present the issue of adverse human reactions to fibrin sealants remains unresolved, and this uncertainty creates a major obstacle for its use. In the not so distant future, there is great hope that the pathophysiology will be elucidated through the combined efforts of several active research groups.

The application of dry fibrin sealant dressings to trauma care in the field is summarized by *Holcomb et al.* [1997a]. Fibrin dressings would be available in several sizes (e.g., 4" x 4" patches) and would be packaged in a manner similar to the standard gauze dressing. Prehospital personnel would unwrap the dry dressing, place it on the wound, and apply pressure for 1-2 minutes. Bleeding from even large blood vessels could be halted through the formation of the "fibrin clot." Other suggested preparations such as dry fibrin sealant powder could be used to bond opposing surfaces, whereas fibrin foam would be useful for noncompressible hemorrhage.

Impact of Dry Fibrin Sealants on the Diagnostic and Treatment Display

Obviously, the detailed knowledge base required for the diagnostic and display system is dependent on the outcome of future fibrin sealant research described in the preceding section. This notwithstanding, we can anticipate several important roles to be played by the knowledge-based system. It is likely that a certain amount of risk will accompany the use of dry fibrin patches. If this is correct, then the knowledge-based system must gather information, assess risk factors, and then determine whether an injury and/or hemorrhage is severe enough to merit a

fibrin patch. This procedure will vary depending on the estimated time it takes to bring the victim to surgery. Civilian trauma victims usually are transported to a hospital within ~20 min, but in the combat situation time scales lengthen to many hours. Although the basic procedure is the same in both cases, the knowledge of certain risk factors may be fundamentally different. For example, the physiological parameters of Army personnel could be determined in advance and become part of the system's knowledge base. This opportunity does not arise in civilian trauma cases. An assessment of the source of hemorrhage may also play a prominent role in determining risk.

Prior to the successful conclusion of the research studies discussed above, one can only speculate as to what the appropriate treatment and monitoring procedures will be for fibrin patches. The currently available information seems to indicate that, once the fibrin patch is applied, the patient will have to be monitored for adverse reactions. Because of the threat of severe hypotension, blood pressure measurements taken at closely spaced intervals are essential. In a worst case scenario, the use of fibrin sealant may require the immediate availability of resuscitative agents.

We can construct a speculative scenario for the treatment of adverse reactions. For example, the pathophysiology may include manifestations of widespread bronchoconstriction, reduced airflow, and mucosal edema. Clincally, there may be a sudden onset of several symptoms: wheezing, chest tightness, difficulty breathing, coughing, increased heart rate, and decreased oxygen saturation. The suggested treatment protocol might be as follows:

1. Remove fibrin patch.
2. Maintain open airway and administer oxygen at 10-15 liters/minute.
3. Maintain open IV access.
4. Administer the following drugs:

    A. <u>Mild to Moderate Reaction</u>

    Benedryl: 25-50 mg via IV

    B. <u>Severe Reaction</u>

    Epinephrine: 0.1-0.3 ml of 1:1000 solution sub-q,

    repeat 2-3 times at 20 min in intervals

    Aminoplylline: 5-7 mg/kg loading dose over 30 min, followed by 15 mg/kg/24 hours via IV drip

In summary, the diagnostic and treatment display has two key tasks to perform regarding dry fibrin patches. First, it must provide an evaluation of risk. This is dependent on three factors: the severity of the injury, level of hemorrhage, and the projected time before the victim will be delivered to a field hospital or trauma center. Second, the unit must guide the user through monitoring procedures for the immediate detection of adverse reactions and suggest a treatment program to counteract known pathophysiologies. Detailed monitoring and treatment procedures require that a consensus be developed pending the outcome of several research studies.

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APPENDIX A

UNIFIED ICEMA AND EMT MANUAL PARAMEDIC PROTOCOLS
(EMT-IA/II/P STANDARD PRACTICE)

ADULT AND PEDIATRIC TRAUMA

PRIORITIES

Scene Safety/Survey
ABC's
Primary Survey
Extrication
Package for Transport
Expeditious transport to closest trauma center if patient meets Load and Go Criteria
Attempt hemodynamic stabilization through fluid resuscitation
"Secondary Survey" Enroute

FIELD ASSESSMENT/TREATMENT INDICATORS:

LOAD AND GO CRITERIA

Any trauma patient with one or more of the following conditions requires expeditious packaging and transportation to the closest trauma center:

1. DIFFICULTY WITH RESPIRATION
a. Airway obstruction unrelieved by mechanical methods (e.g. jaw thrust, suction, forceps)
b. Conditions resulting in possible inadequate breathing
        1'. open chest wound (sucking chest wound)
        2'. flail chest
        3'. hemo/pneumothorax, simple or tension
        4'. blunt chest injury
c. Respiratory arrest

2. DIFFICULTY WITH CIRCULATION:
a. Traumatic cardiopulmonarv arrest
b. Shock
        1'. hemorrhagic
        2'. spinal (spinal cord penetration)
        3'. myocardial contusion
        4'. pericardial tamponade
c. Absence of peripheral pulses
d. Chest contusion with arrythmia and/or hemodynamic instability

3. DECREASED LEVEL OF CONSCIOUSNESS.
Head injury with decreased level of consciousness and/or Glasgow Coma Score <13

4. AXIAL (SPINAL) AND SOFT TISSUE TRAUMA:

a. Tender and distended abdomen
b. Obvious pelvis instability
c. Bilateral femur fracture
d. Any obvious long bone fracture which results in absent distal pulses
e. Limb amputations (proximal to wrist and ankle)

If in the EMT-P's judgment, the patient has been involved in a trauma incident, which because of a high energy exchange, causes the EMT-P to be highly suspicious that the patient is severely injured, the patient should be entered into the trauma system.

PARAMEDIC SUPPORT PRIOR TO BASE HOSPITAL CONTACT:

(GRAY ZONE: AT ANY POINT ON LIST PATIENT CAN BE DECLARED LOAD-AND-GO)

1. Scene Survey
a.   secure scene safety
*b.   determine mechanism of injury
*c.   determine number of victims

2. Assess and maintain airway with in-line axial stabilization
a.   chin lift/jaw thrust
b.   clear airway of foreign bodies
c.   BVM with supplemental oxygen as clinically indicated
d.   oro/nasopharyngeal airway as needed
e.   endotracheal, nasotracheal intubation (adults only) or needle cricothyrotomy as indicated to protect and maintain airway

3. Ventilatory Support
a.   expose chest and neck
*b.   determine rate and effort of respirations
c.   inspect and palpate chest
d.   assess neck for tracheal deviation or JVD
e.   auscultate chest
f.   seal open chest wounds
g.   alleviate tension pneumothorax (needle thoracostomy)

4. Circulatory Control
a.   control external hemorrhage
b.   place anti-shock trousers for isolated blunt abdominal trauma or to splint extremity fractures

5. Assess for pulses
*a.   palpate radial pulse. if present B/P >80 mm/Hg
*b.   if no radial pulse palpable, palpate femoral, if present B/P >60 mm/Hg
*c.   if no femoral pulse palpable, palpate carotid pulse, if present B/P >40 mm/Hg
Note: B/P cuff generally not used in primary survey. B/P taken either by palpate or with audio using a stethoscope.

6. Evaluate perfusion
*a.   assess pulse rate and description
*b.   assess capillary refill - immediate, delayed, none
*c.   assess skin color - normal pale. ashen, cyanotic, flushed

7. Assess neurologic status per Glasgow Coma Scale
*a.   eye opening - none. to pain. to voice, spontaneous
*b.   best verbal response - none. incomprehensible, inappropriate, confused, oriented
c.   motor response - none, extension, flexion, withdrawal, purposeful. obedient

8. Determine chief complaint
*TRAUMA CENTER/BASE HOSPITAL ASSESSMENT

PROCEDURES

LOAD-AND-GO PATIENTS

1. Package patient for transportation
2. Expeditious transportation to closest trauma center
3. Once enroute initiate large bore IV/IO (blood Y tubing) wide open for B/P <90 (absence of palpable peripheral pulses), 100 ml/hr for B/P >90 (palpable peripheral pulses). For pediatric patients with absence of peripheral pulses, administer 20 cc/kg NS boluses to maintain peripheral pulses
4. Contact Trauma Base Hospital (if unable, contact closest Base Hospital)
5. Cardiac monitor
6. Initiate second large bore, IV/IO wide open for B/P <90 (blood Y tubing if available)
7. Manage special considerations (below), place splints and dressings as needed
8. Complete secondary survey to include patient response to therapy
9. Repeat vital signs
10 Update Base Hospital

ALL OTHER TRAUMA PATIENTS

1. Complete rapid secondary survey
2. Manage special considerations, place splints and dressings as needed
3. Package patient for transport

4. Begin transport to most appropriate facility
5. Initiate IV access to infuse at 100 ml/hr
6. Contact Base Hospital
7. Cardiac monitor
8. Repeat vital signs
9. Update Base Hospital

BASE HOSPITAL MAY ORDER:

**1. Establish additional IV/IO lines enroute
**2. Treat special considerations as clinically indicated

*** May be done during radio communication failure*

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ABDOMINAL TRAUMA:

1. Blunt trauma:
     a. May present with rigidity, ecchymosis, pain, shock
     b. AST may be used if hypotension persists despite fluid resuscitation

2. Impaled object:
     a. Attempt to stabilize the object. Do not remove unless object interferes with CPR
     (consult Base Hospital Physician if time allows)

3. Eviscerating trauma:
     a. Cover eviscerated organs with sterile saline soaked gauze
     b. Do not replace organs into abdominal cavity
     c. In case of abdominal evisceration, also apply occlusive dressing (tape on all four
     sides)
          This dressing may be:
          (1) A dry clean sterile dressing
          (2) Sterilized plastic wrap
          (3) Sterile Vaseline gause
          (4) Sterile aluminum foil

4. Genital injury:
     a. Apply direct pressure to actively bleeding sites
     b. Cover genitals with sterile saline soaked gauze
     c. Treat amputated parts per amputations (described elsewhere)

ABDOMINAL TRAUMA MANAGEMENT

As with chest trauma, the two factors dictating management of blunt or penetrating injury are the mechanism and the signs and symptoms of hypovolemic shock.

1. Repeat vital signs at a minimum of every 10 minutes.

2. Reexamine abdomen frequently, noting distention, tenderness, guarding.

3. Do not return bowels or viscera back to abdomen. Cover with sterile, moist (if sterile solution is available) dressings, then cover completely with occlusive dressing.

Do not remove objects impaled in the abdomen. Stabilize with gauze packing.

Elevate extremities as required to maintain blood pressure.

Hypotension may be treated with anti-shock trousers (MAST). With pregnant patients, do not inflate the abdominal segment.

PROCEDURE FOR PREPARATION
OF TRAUMA VICTIM FOR TRANSPORTATION

ALL EMT - P'S, EMT - II'S AND MICN'S IN THE ICEMA REGION WILL FOLLOW THE POLICIES AND PROCEDURES BELOW IN THE TREATMENT OF TRAUMA VICTIMS:

DO NOT DELAY TRANSPORT ATTEMPTING TO CARRY OUT THESE PROCEDURES:

If the ambulance is on the scene, then the trauma victim(s) should be loaded into the ALS/LALS unit and a complete secondary survey completed enroute to the facility the Base Hospital has determined is the most appropriate.

IMMEDIATELY AFTER THE ARRIVAL ON SCENE AND/OR PRIOR TO EXTRICATION OF THE TRAUMA VICTIM:

1.   Assure Airway, Breathing and Circulation (ABC's)
2.   Control active bleeding by direct manual pressure
3. O_2 10-15 liters per minute by mask as indicated
4.   Stabilize the cervical spine
5.   Do not remove any impaled objects
6.   Do not administer any oral fluids to victim(s)

FOLLOWING EXTRICATION OF THE TRAUMA VICTIM:

Place Patient on anti-shock trousers on the backboard

IF NO AMBULANCE ON SCENE COMPLETE AS MANY OF THE FOLLOWING PROCEDURES AS APPLY:

1. Stabilize head and neck with sandbags, adhesive tape and/or straps
2. Cover open chest wound with vaseline gauze
3. Cover eviscerated bowel with saline soaked pads
4. Splint fractures being sure to check distal pulses and sensation both before and after the splinting procedure

TRAUMA PHYSICAL EXAMINATION

(NOT A LOAD-AND-GO SITUATION, GSW WITHOUT MAJOR TRAUMA: E.G., PATIENT WALKING ABOUT)

Each Paramedic or EMT-II will follow all assessment criteria, protect the cervical spine, and assess the trauma patient as follows in the order given:

PRIMARY SURVEY

1. ABC's -- Airway, breathing and circulation (to include control of bleeding).

2. Vital Signs -- Systolic blood pressure, respiratory rate, respiratory effort and capillary refill.

3. Neurological Assessment -- Glascow Coma Scale (eye opening, verbal response, and motor response)

4. History -- Mechanism of injury

STOP

5. REPORT the above elements to the Base Hospital. The physician or MICN will compute the trauma score and direct the Paramedic or EMT-II to the appropriate receiving hospital.

PRIMARY SURVEY (EMT MANUAL)

The primary, basic function of all persons involved in emergency medical care is the rapid assessment, management, and reassessment of a patient's ABCs: Airway, Breathing, and Circulation. The EMT has the added responsibility to perform a rapid assessment of the scene to determine (a) environmental dangers, (b) the number of patients to be treated, (c) the mechanism of injury, and (d) the problems of immediate extrication. In serious illness or trauma, aggressive management of major ABC problems is vital. The patient will die if these primary functions are neglected or managed carelessly.

A = AIRWAY

1. Is it open?
Check for movement of air: look to see the chest rise, listen
for airflow; feel chest wall for movement and crepitus, check
for stoma.

2. Is patient positioned properly?
Check head tilt and neck or chin lift; jaw thrust for face or neck
trauma (maintaining in-line cervical traction).

3. Are respirations noisy, gurgling, or labored?
Check for partial obstruction, fluids, excess salivation.

4. Look for inspiratory retractions at supraclavicular and intercostal
space, diaphragmatic movement only without airflow.
Check for complete obstruction.

B = BREATHING

1. Is patient breathing?
Resuscitate mouth-to-mouth or mouth-to-mask; send for bag
mask.

2. Depth of respirations?
Inspect chest movement.

3. Gasping respirations?
Palpate for flail, sucking chest wounds.

4. Rates?
Rates <10/min should be assisted.

5. Unusual patterns?
Cerebral insults produce specific patterns to record.

C = CIRCULATION

1. Is there a palpable pulse?
Check carotid pulses; if none, do cardiopulmonary resuscitation
(CPR). Use femoral pulse to confirm circulation with CPR.

2. Is pulse rate <55 or >180/minute?
Check for signs of inadequate perfusion.

3. Is pulse irregular?
Compare apical and radial pulses for discrepancy, then check
irregularities with electrocardiogram (EKG) monitor, if one is available (and EMT is so trained).

4. Is there visible external hemorrhage
Control external bleeding.

5. Is there suspected internal bleeding?
Begin treatment for shock.

ALTERED LEVEL OF CONSCIOUSNESS

PRIORITIES:

ABC's
Determine possible etiology.
Determine degree of physiological distress.
Begin treatment in the prehospital setting.
Consider early transport based upon clinical findings.

FIELD ASSESSMENT/TREATMENT INDICATIONS:

1. Determine cause of altered mental status through signs and symptoms. For Glasgow coma Scale <15, or unclear etiology consider AEIOU TIPS.
2. Assess for suspected narcotic overdose.
3. Assess for suspected hypoglycemia.
4. Assess for traumatic injury.
5. Expeditious transportation for patients with unmanageable airway, deteriorating vital signs or increasing neurological deficits.
6. Ensure rescue personnel safety prior to administration of naloxone.

PARAMEDIC SUPPORT PRIOR TO BASE HOSPITAL CONTACT:

1. Assure and maintain airway patency.
2. Position patient in left lateral position if altered gag reflex.
3. High flow oxygen unless otherwise clinically indicated. Be prepared to support ventilations with appropriate airway adjuncts. Endotracheal intubation may be contraindicated for patients that are known diabetics or narcotic overdoses prior to naloxone or dextrose administration.
4. Cardiac monitor.
5. Draw blood sample and determine blood glucose by glucose monitoring stick if available
6. IV access TKO. Give 500 ml fluid challenge if B/P <90 with associated shock symptomatology (for the hypotensive pediatric patient, reference protocol #9001 for intravenous flow rates).
7. Administer dextrose 50%, 25 Grams (50 ml) IVP (Pediatric dose - 1 ml/kg) for suspected hypoglycemia.
8. Administer glucagon 1 mg IM/SC, if unable to establish IV, one time only. Pediatric dose .025 mg/kg with maximum dose of 1 mg, may be repeated 1 time after 20 minutes, for pediatric only.
9. Administer naloxone 2.0 mg IVP (Pediatric dose - ..01 mg/kg) for suspected narcotic overdose. Anticipate possible withdrawal syndrome in the narcotic dependent patient.
10. Assess response to therapy, repeat vital signs and contact Base Hospital.

BASE HOSPITAL MAY ORDER THE FOLLOWING:

*1. Repeat 25 Grams (50 ml) of dextrose 50% IVP if no response to initial therapy
*2. Repeat naloxone 2.0 mg IVP (Pediatric dose - .1 mg/kg) may be repeated every 2-3 minutes if no response to initial therapy.
*3. If fluid challenge given, adjust IV rate to 300 ml/hr if B/P >90, if B/P <90 give fluid challenge in 500 ml increments to obtain a B/P >90.

* May be done during radio communication failure.*

LEVEL OF CONSCIOUSNESS (EMT MANUAL)

In addition to the assessment of the ABCs, it is necessary to make initial assessment of the patient's level of consciousness. A quick assessment can be performed by determining the Glascow Coma Score (see Appendix 6). Other measures of neurologic status include state of mind, level of consciousness. and pupillary response.

1. State of mind.
a. Is the patient oriented? Knows who he/she is, where he/she is, approximate time of day, circumstances of the event.

2. Level of consciousness.
a. Alert: completely awake and acting appropriately.
b. Lethargic: sleepy, but aware of surroundings.
c. Stuporous: will awaken to vocal stimuli, prefers to remain asleep.
d. Obtunded: will awaken to painful stimuli only.
e. Comatose: nothing will awaken patient.
Note: Medical terms such as "stuporous" or "obtunded" can be imprecise. meaning different things to different people, even within the medical community. An alternative approach characterizes levels of consciousness on the basis of response, as follows:
a. Alert.
b. Responsive to verbal stimuli: awakens only when spoken to.
c. Responsive to painful stimuli: awakens only when ears are pinched.
d. Unresponsive.

3. Pupillary condition.
What is pupillary response to bright light? Do pupils constrict? Check for deviated gaze. Check pupillary size.

4. Chronic illness.
If the patient is conscious, inquire about chronic illness, current medications, allergies. If the patient is unconscious, check for medical alert wallet card. bracelet, or necklace.

5. Reassessment.
Repeat assessment of ABCs during the secondary exam and treatment phase to make sure that the patient's condition is not worsening. Evaluation of pulse rate, respiratory rate, and blood pressure should be repeated at 10-minute intervals.

SECONDARY SURVEY

This assessment will be done after the Paramedic or EMT-II has received directions from the Base Hospital. It should be performed while enroute to the receiving hospital if no extenuating circumstances exist. such as a need for extrication.

6. Head and Face -- wounds, depressions, deformations, blood or fluid from ears or nose, bruises around the eyes and/or behind the ears, pupillary response.

7. neck -- Tracheal deviation, wounds, protusion of the spine, bruises, crepitus (subcutaneous emphysema)

8. Chest -- Wounds, bruises, flail chest, heart sounds, breath sounds, crepitus, presence of bowel sounds in the chest area. equal symmetrical chest expansion, impaled objects.

9. Back -- wounds bruises, crepitus, impaled objects, deformations, protrusions.

10. Abdomen -- Wounds, bruises, rigidity, distension, bowel sounds, impaled objects, eviscerations.

11. Pelvis -- Crepitus, pain on pressure, deformations, bloody urine.

12. Extremities -- Wounds, fractures, discoloration, motor sensory loss, pulses, positioning, temperature, color.

13. Report complete assessment enroute.

SECONDARY SURVEY (EMT MANUAL)

The head-to-toe exam is called the secondary survey and provides additional and specific information about the patient's condition. As it is being done, ask the patient about the chief complaint and associated symptoms. The secondary survey is divided into medical and trauma sections. This helps refine the approach to the special problems in each specific category. The equipment required includes a stethoscope, blood pressure cuff, and pen light.

MEDICAL SURVEY

Head, Eyes, Ears, Nose, Throat/Neck (HEENT)

1. Look for skin discoloration, moisture. drooling, blood, nasal flaring, frothy or bloody sputum, bloody emesis, facial sagging, drooping eyelid(s), deviated gaze, unequal pupils, eyelids held closed by patient, color of conjunctiva, distention of neck veins, retractions of accessory muscles at base of neck, presence of stoma, deviated trachea.

2. Listen for stridorous speech, whispered speech, snoring, gurgling, coughing.

3. Feel for tenderness, subcutaneous air, stiffened neck, bulging fontanel (infants).

4. Smell ketones, vomit, alcohol, fecal-like odor.

Chest

1. Look for respiratory rates and patterns: rapid (tachypnea), slow (bradypnea), shallow, irregular, painful (splinted), periodic (Cheyne-Stokes). Look for chest wall movement: intercostal retractions, barrel chest, obvious malformations.

2. Listen for absence of lung sounds, presence of rales or wheezes in either lung field.
a. Patients who can sit: use stethoscope to listen to posterior thorax at apex, mid-scapula, and base, starting at the base and moving toward the head to compare both sides (Fig. *2-1*). Have the patient breathe deeply with mouth open while stethoscope is being used.
b. Patients who are unable to sit: listen to anterior part of chest at second intercostal space lateral to sternum.

Abdomen

1. Look for changes in general contour, distention, presence of pulsatile mass lateral to midline; note scars, location.

2. Feel. With the patient lying down, start at the point furthest from area stated to be painful by patient. Patient may flinch or tense the muscles because of ticklishness or the examiner's cold hands. Confirm all reactions with patient verbally.
a. Begin with gentle palpation: move fingers of one hand over the entire abdominal area, noting areas of tenderness, increased muscle resistance (spasm), or solid masses.
Deep palpation: with second hand pressing on top of the fingers of the first hand, slowly compress to a depth of 45 cm. Palpate the complete abdomen, noting tenderness or solid masses.
If there is a pulsating mass along midline between epigastrium and umbilicus, identify and mark the extent of the pulsatile mass, and check femoral pulses bilaterally for equal strength.

Extremities

1. Look for skin discoloration, moisture. texture, obvious deformities, symmetry, inflammation, edema of ankles and lower leg (note and mark extent), scars, needle marks, cyanosis of nail beds.

2. Feel for bilateral radial and/or pedal pulses. skin turgor of hands and arms, pitting edema (ankles, lower legs), equal **bilateral** grip strength, foot extension strength, equal movement, range of motion: touch for sensation.

TRAUMA SURVEY

The physical examination in patients with medical problems depends upon a careful interrogation and elicitation of past history. This directs the examiner to specific problem areas. The trauma patient must have a head-to-toe systematic examination. Knowing the mechanism of injury is important in understanding the extent of injury to the trauma patient. The EMT in charge, or his/her partner, must assess the accident scene for possible causes of injury. Remove or rearrange enough clothing to examine all parts of the body and to avoid missing hidden injuries.

Head, Eyes, Ears, Nose, Throat/Neck (HEENT)

Scalp
1. Look for areas of hemorrhage, hematoma, depressions. punctures.

2. Feel for deformity, blood. Neck must remain stable during exam; maintain anatomic normal alignment.

Eyes
1. Look for constriction dilation, unequal pupil size, deviated gaze, contact lenses, foreign objects,

A-12

conjunctival discoloration, ecchymosis around eyes (raccoon eyes), other gross injuries. With pen light, check pupillary response to light, ability to follow an object through the full range of motion.

2. Feel for resistance by patient to opening eyelids, if behavioral disorder is suspected.

Ears
1. Look at outer ear and inside canal. *Look* for hemorrhage, drainage of clear or pink fluid, discoloration behind ear (mastoid area).

Nose
1. Look for hemorrhage, deformity, drainage of clear or pink fluid, nasal flaring.

Face
1. Look for wounds, discoloration.

2. Feel for deformity of cheekbones, instability of upper and lower jaw.

Mouth

1. Look for wounds, hemorrhage. discoloration (cyanosis, ecchymosis around lips), foreign objects, loose or missing teeth.

2. Listen for stridor, gurgling, occlusion.

Neck (Anterior and Posterior)

1. Look for wounds, distended neck veins, stoma, deviated trachea, suprasternal retractions.

2. Feel for bony deformities, tenderness, muscle spasm, subcutaneous air.

Chest

1. Look for supraclavicular or intercostal retractions, wounds, discoloration, paradoxical respiratory movement (flail, diaphragmatic breathing), deformity.

2. Listen for sucking wounds, altered breath sounds (diminished or absent), wheezes or rales (anterior at second intercostal space and posteriorly above scapula), muffled or distant heart sounds (at apex, under left nipple).

3. Feel for deformity, tenderness, crepitus, muscle spasm; compress mid-sternum, gently, then firmly.

Abdomen

1. Look for wounds, discoloration, distention.

2. Feel for tenderness, muscle spasm (voluntary and involuntary). Palpate all four quadrants, gently, then deeply.

Lumbar Spine

1. Feel for tenderness, deformity, muscle spasm; minimize movement.

Pelvis

1. Look for wounds, discoloration, deformity.

2. Feel for deformity, tenderness. stability. Gently, then firmly compress iliac crests toward midline, then downward. Palpat femoral pulses bilaterally for equality.

Buttocks/Genitalia

1. Look for wounds, discoloration.

2. Feel for tenderness.

Extremities

General

1. Look for wounds, deformity (swelling, angulation), discoloration (especially check skin color distal to an injury); ability to move spontaneously and on command.

2. Feel for tenderness, deformity.
a. *Sensation:* check response to gentle touch (with patient looking away); then to painful stimuli.
b. *Movement:* pain on movement, ability to move spontaneously and against resistance.
c. *Pulses.* check distal circulation.

Legs

1. Look for ability to wiggle toes.
2. Feel for ability of foot to push against resistance.
Arms

1. Look for ability to wiggle fingers.
2. Feel for strength and equality of grasp.

RECORD VITAL SIGNS

1. Respiratory rate

2. Pulse rate.

3. Blood pressure. Determine in both arms.

4. Skin: temperature, color, moistness.

5. State of consciousness. Calculate Glascow Coma Score.

6. Calculate Severity Index Score, if indicated.

SHOCK (EMT MANUAL)

Shock refers to a lack of adequate tissue perfusion because of insufficient blood flow to vital organs. It can be caused by hypovolemia, inadequate cardiac function, or vasodilation (relative hypovolemia).

HYPOVOLEMIC SHOCK

Definition

A loss of circulating blood volume resulting in inadequate tissue perfusion.

Causes

1. External fluid loss.
   a. Hemorrhage (any obvious source).
   b. Abdominal tract (vomiting, diarrhea).
   c. Kidney (diabetes, diuretics).
   d. Skin (burns, sweating).

2. Internal fluid loss.
   a. Fracture.
   b. Ascites (peritonitis, pancreatitis, cirrhosis).
   c. Intestinal obstruction.
   d. Internal bleeding (hemothorax [chest], rupture of organ or great vessels into abdomen, rupture of ectopic pregnancy).

History: Subjective Reports

External hemorrhage or fluid loss is usually obvious. Internal losses may be more difficult to determine. A history of abdominal pain or complaints with postural hypotension, fainting, and/or lightheadedness in an upright posture suggests acute abdominal hemorrhage. Alcoholics are particularly prone to gastrointestinal bleeding.

Examination: Objective Physical Findings

Determine the postural blood pressure (not necessary when the patient has a supine systolic blood pressure of 80 mm Hg or less). Return patient to supine position immediately if patient becomes faint in upright position.

1. Shock is often classified into mild, moderate, or severe.
a. Mild shock.
   i. Postural pulse increase of 10 to 20 beats per minute.
   ii. Postural systolic blood pressure drop of 10 mm Hg.
   iii. Flat neck veins while patient is supine.
b. Moderate shock.
   i. Postural pulse increase of 20 beats per minute.
   ii. Postural systolic blood pressure drop of 20 mm Hg.
   iii. Pale, sweaty, anxious, agitated.
   iv. Confused mental state.
c. Severe shock.
   i. Non-recordable blood pressure in any position.
   ii. Pale, cyanotic, sweating, tachycardia.
   iii. Confusion or coma.
   iv. Apparently absent neck veins while patient is supine.

2. A convenient way to categorize shock due to acute hemorrhage is that proposed by the American College of Surgeons. Acute hemorrhagic shock is divided into four classes. The classification is valid only for acute hemorrhage and is intended only as a guide. Tachycardia may not be seen in the elderly. Alcohol intoxication may alter the anticipated clinical signs of acute blood loss.

3. Continue to monitor patient with frequent reassessment.

EMT Management

1. Positive pressure to external hemorrhage sites.

2. Oxygen, positive pressure ventilation as needed.

3. Consider use of anti-shock trousers (MAST), if trained in use.

4. Supine position, elevated lower extremities (if patient is on a backboard, raise foot of board).

EMT Special Considerations

Patients require volume replacement with whole blood or other fluids. Often, surgical intervention is required. Rapid recognition of shock condition, control of external hemorrhage, and delivery to the hospital are the key ingredients in patient survival.

APPENDIX B

OPERATIONAL DEFINITIONS

TRAUMA SCORE

MECHANISM OF INJURY CHIEF COMPLAINT:

RESPIRATORY RATE

Number of respirations in 15 seconds multiplied by four

RESPIRATORY EXPANSION

Retractive -- use of accessory muscles or intercostal muscle retraction

SYSTOLIC BLOOD PRESSURE

Systolic cuff pressure; either arm
              -- auscultate or palpate
No Pulse   -- no carotid or other pulse

CAPILLARY REFILL

Normal   -- nail bed, forehead, or lip mucosa color, refill in 2 seconds or time taken
to   mentally repeat "capillary refill"

Delayed   -- more than 2 seconds capillary refill

None   -- no capillary refill

EYE OPENING

Opens eyes spontaneously or to stimuli

BEST VERBAL RESPONSE

Arouse with voice or painful stimulus

BEST MOTOR RESPONSE

Response to command or painful stimulus

PUPILLARY STATUS CHART

Pupil	Equal		Unequal	
	Reactive	*Unreactive*	*Reactive*	*Unreactive*

Dilated	Hypoxia
	Pain
	Drugs
	  alcohol
	  stimulants
	Dim light
	  (normal)
		Anoxia
		Seizures
		Drugs
		  glutethimide
		    (Doriden)
		  belladonna
		    (atropine)
		  psychodelics
				CVA
				Head injury
				Eye trauma

Mid	Normal	Hypothermia Methanol	Normal in 4% of popu- lation	Glass eye

Constricted
 	
to
Pinpoint
	Bright light
	  (normal)
		Drugs
		  opiates
		  barbiturates
		Brainstem
		  injury		

For the abdominal trauma study, dilated pupils are possibly indicative of a 4-6 min absence of O_2 to the brain. A PVS may exist or brain death may have occurred. This is a consideration when triage is necessary.

CALCULATING THE TRAUMA SCORE

The Trauma Score is a numerical grading system for estimating the severity of injury. The score is composed of the Glasgow Coma Scale and measurements of cardiopulmonary function (see score card below). Each parameter is given a number, high for normal and low for impaired function. Severity of injury is estimated by summing the numbers. The lowest score is 1, and the highest score is 16.

Note: The Revised Trauma Score (RTS) is also used in this study. It is discussed in detail in the main body of the report.

Trauma Score Card

A SYSTOLIC BLOOD PRESSURE		B RESP RATE		C RESP EFFORT		D CAPILLARY REFILL	
>90	= 4	10-24	= 4	Normal	= 1	Normal	= 2
70-90	= 3	25-35	= 3	Shallow or		Delayed	= 1
50-69	= 2	>35	= 2	Retractive	= 0	None	= 0
<50	= 1	<10	= 1				
0	= 0	0.	= 0				

GLASCOW COMA SCALE (G.C.S.)

1 EYE OPENING		2 VERBAL RESPONSE		3 MOTOR RESPONSE		4 G.C.S POINTS	
Spontaneous	= 4	Oriented	= 5	Obedient	= 6	(1+2+3)	
To Voice	= 3	Confused	= 4	Purposeful	= 5	14-15	= 5
To Pain	= 2	Inappropriate	= 3	Withdrawal	= 4	11-13	= 4
None	= 1	Incompre-		Flexion	= 3	8-10	= 3
		hensible	= 2	Extension	= 2	5-7	= 2
		None	= 1	None	= 1	3-4	= 1

TRAUMA SCORE = _____
(A+B+C+D+4)

GLASGOW COMA SCALE OPERATIONAL DEFINITIONS

EYE OPENING

Spontaneous	Eye opening is spontaneous if the patient's eyes are already open at the time of the assessment with no stimulation other than that of the existing ambient environment. The patient can close his eyes to command. This eye opening response implies an intact reticular activating mechanism and a functioning arousal mechanism.
To Voice	If the patient's eyes are not open at the time of the assessment, a response to voice is present if the eyes open when the patient's name is spoken or shouted.
To Pain	If verbal stimulation is unsuccessful in eliciting eye opening, a response to pain is present if the eyes open when a standard pain stimulus is applied.
None	No eye response is present if the above attempts at stimulation are unsuccessful

BEST VERBAL RESPONSE

Oriented	After being aroused, the patient is asked name, place and date. The patient is oriented if the answers given are correct.
Confused	The patient is confused if the individual cannot answer the questions regarding name, place and date accurately but is still capable of producing phrases, sentences, or conversation exchanges.
Inappropriate	In this state, the patient cannot produce phrases, sentences or conversational exchanges but can produce an intact word or two. These words may be elicitable only in response to physical stimulation and may frequently be obscenities or relative's names.
Incomprehensible	In this state, the patient can produce groans, moans, or unintelligible mumblings, but cannot produce an intact word in response to stimulation.
None	In this state, the patient does not respond with any phonation to any stimulation no matter how prolonged or repeated

NOTE: Tracheal or esophageal intubation renders assessment of verbal response invalid

BEST MOTOR RESPONSE

Obedient   In response to instructions, whether verbal or written, or through gestures, patient shows ability to comprehend the instruction and to physically execute it. A common example is the command to hold up two fingers.

Purposeful   When a standard painful stimulus is applied, the patient may move limb or body away from stimulus in a purposeful manner or attempt to push stimulus away.

Withdrawal   If the patient does not obey commands, the standard pain stimulus is applied. Withdrawal is present if:
1. The elbow flexes,
2. The movement is rapid,
3. There is no muscle stiffness, and
4. The arm is drawn away from the trunk.

Flexion   Flexion is present if:
1. The elbow flexes,
2. The movement is slow,
3. Muscle stiffness is present,
4. The forearm and hand are held against the body, and
5. The limbs hold a hemiplegic position.

Extension   Extension is present if:
1. The legs and arms extend,
2. Muscle stiffness if present, and
3. External rotation of the shoulder and forearm occurs.

None   Maximum standard pain stimulation produces no motor response.

NOTE: Spinal cord injury may invalidate motor assessment in this form